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MULTIPLE GENERATION OF PARTICLES IN NUCLEON-NUCLEON AND π-MESON-NUCLEON COLLISIONS IN THE REGION OF ACCELERATOR ENERGIES

Oleg Czyzewski and Roman Holynski

- Poland -

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Multiple Generation of Particles in Nucleon-Nucleon and π-Meson-Nucleon Collisions in the Region of Accelerator Energies

- Poland -

[Following is a translation of an article by Oleg Czyzewski and Roman Holynski, Department VI, Institute of Nuclear Research (Zaklad VI Instytutu Badan Jadrowych) Krakow, in Postepy Fizyki, Vol XII, No 1, 1961, Warsaw; pp 71-87.]

The problem of multiple generation of mesons is closely connected with our concepts of nucleons. At the time when it seemed that the statistical theories started by the famous theory of Fermie explained in a satisfactory manner the phenomenon of multiple generation one could visualize a nucleon as a body without structure. However, in the region of highest energies ($>10^{11}$eV) there seems to appear an outline of facts indicating that the process of multiple production cannot be described with the aid of statistical-hydrodynamic theories.[1] Recently, studies of multiple production in the region of accelerator energies also encountered a series of difficulties in the interpretation of this phenomenon with the aid of the statistical theory and it appears that we must introduce to the new interpretation concepts the structure of the nucleon.

The limit of the generation of π mesons in the system of the center of mass of two colliding nuclei constitutes 140 MeV, which corresponds in the laboratory system to 290 MeV. Below this energy the collisions are only elastic. The active section for elastic collisions σ_{el} decreases with an increase of energy, while the active section for inelastic collisions σ_{inel} increases in the region of 290 MeV to 1 GeV and here reaches a value which in the boundary of energy to 10 GeV does not undergo any greater change. Fig. 1 shows active elastic, inelastic and full sections as a function of energy.

Studies concerning inelastic collisions n-n and π -n are conducted essentially in four centers: Brookhaven (cosmotron 2.75 GeV), Berkeley (bevatron 6.36 GeV), Dubna (synchrophasotron 9.2

[1] On this subject compare the article: J. Bartke, R. Holynski, Postepy Fizyki, 10, 309 (1959).

GeV) as well as in CERN in Geneva (a 28 GeV accelerator recently placed in operation). The studies, which will be discussed below, derive principally from Berkeley and Dubna. The results gotten in this field in CERN have not yet been published and certain meager data derive from private communiques. Studies concerning multiple generation in the bounds of accelerator energies yield a series of valuable characteristics of these processes such as: number of the generated mesons, their angular distribution and energy distribution; they estimate the coefficient of inelasticity of these collisions, etc. The wavelength of de Broglie's nucleon in the system of the center of mass for energy of 2.24 BeV (Brookhaven) is $\lambda = 1.92 \cdot 10^{-14}$ while for 9 BeV $\lambda = 0.96 \cdot 10^{-14}$, i.e. considerably less than the radius of action of the nucleon; it can therefore be expected that these experiments will also yield certain information on the structure of the nucleon.

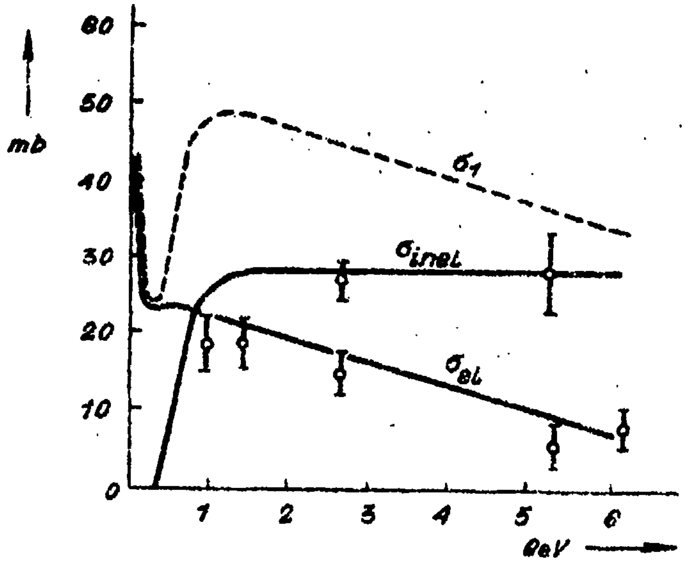


Figure 1. Active sections for p - p collision: elastic σ_{el} unelastic σ_{el} and full σ_t, as a function of energy.

Experimental Data Concerning Proton-Nucleon Collisions

We shall begin the review of experimental data with the studies made in the Laboratory of High Energies in Dubna. In a number of these studies very similar results were obtained and one can reach many common conclusionsregarding them. In the work of N.P. Bogaczew and others, the angular and energy distributions of secondary particles generated in proton-nucleon collisions were studied. The work is made with the aid of the emulsion

technique. A block of emulsion of the NIKFI-R type was bombarded with a cluster of protons accelerated in synchrophasotron to an energy of 9 BeV. Subsequently, in examining the plates alongside the traces of the primary protons a search was made for nuclear interactions. Along a length of 978 meters 2673 cases of this type were found and a mean path of a free interaction equal to 37.3 ± 0.3 centimeters was designated. A majority of these interactions are collisions of protons with various type nuclei of the emulsion, and only a few cases are collisions of a proton with a free proton (nucleus of hydrogen) or a proton with a quasi-free nucleon. The authors have applied a series of criteria which would permit to select a relatively free sample of proton-nucleon collisions. There were selected 170 cases with an even number of traces (proton-proton collisions) as well as 110 cases with an odd number of traces (proton-neutron collisions). The average number of loaded traces was 3.22 ± 0.12 for p-p collisions and 2.62 ± 0.13 for p-n collisions. Table 1 gives in percent the number of p-p and p-n collisions depending on the number of loaded traces.

krotność	1	2	3	4	5	6	7	8
p-p		45,8 ± 5,2		44,7 ± 5,1		8,8 ± 2,3		1,2 ± 0,8
p-n	33,6 ± 5,5		52,7 ± 7,9		12,7 ± 3,4		0,9 ± 0,9	

Table 1

a) number

In work the identification and designation of energy was conducted only for slow particles, having an ionization higher than 1.4 times minimal ionization. There were designated energies of 53 protons and 9 mesons π in collisions p-p and 22 protons and 5 mesons π in collisions p-n.

These data permit certain conclusions to be advanced about the angular distribution of protons in the system of the center of mass (C.M.) and to estimate the percent of energy of the primary nucleon transferred for the generation of secondary particles. For p-p collisions in the region of 155°-180° in the C.M. system 53 protons were found. The assumption of their isotropic distribution in the C.M. system is senseless, since then, for 170 interactions under study, we shall obtain 1230 protons.[2] Hence the angular distribu-

[2] $$\frac{53}{\frac{1}{2}\int_{155^\circ}^{180^\circ}\sin\theta\,d\theta} = \frac{0,53}{0,047} = 1230.$$

tion of protons in the C.M. system should be strongly anisotropic. If we assume that after collision we have one or two protons among the secondary particles, then the half-angle in the C.M. system for the front as well as the rear hemisphere will be correspondingly 20° or 30°. The average velocity of the identified protons is 1380 ±-40 MeV/C in p-p collisions and 1250 ± 50 MeV/C in p-n collisions. Having this data it is possible to evaluate the energy transmitted by the primary particle to the mesons in the laboratory system

$$E_{\pi lab} = 2\gamma_c(E - \bar{E}_p),$$

where $\underline{E}$ = energy of the proton in the C.M. system before collision
$\bar{E}_p$ = average energy of the proton after collision.
and to evaluate

$$\frac{E_{\pi lab}}{E} = 30\%.$$

This result is rather the lower limit of this relation, since protons were only identified in the region of angles 150° -180°. It can be expected, however, that the average velocity of protons flying at an angle less than 155° in the C.M. system will not be significantly different and that the relation $\varkappa$ will not undergo any greater change. This result permits to calculate the mean energy of the π meson (on the assumption that in one collision there is one proton among the secondary particles), which is, in the laboratory system, about 800 MeV. and in the C.M. system, about 340 MeV.

In order to obtain the angular distributions of secondary particles in the C.M. system we transform the measured laboratory angles, with the aid of the formula:[3]

$$\gamma_c \operatorname{tg} \Theta_i = \frac{\sin \bar{\Theta}_i}{m + \cos \bar{\Theta}_i}, \qquad (1)$$

Where $\gamma_c = 1/\sqrt{1-\beta_c^2}$, β_c = speed of the center of mass in the laboratory system

$m = \beta_c/\bar{\beta}_i$ designates the relation of the speed of the system of center of mass to the laboratory system's relation to the speed of the transformed particle.

In collisions of a sufficiently high energy we can assume that m = 1 and then

[3] Symbols with a dash on top designate magnitude in C.M.

$$\gamma_c \mathrm{tg}\, \Theta_l = \mathrm{tg}\, \frac{\Theta_l}{2} \qquad (2)$$

Figures 2a, b, c, and 3a, b, c represent angular distributions of secondary particles (on the assumption that m = 1) in p-p and p-n collisions for various numbers. It is seen that for n = 2 and n = 3 the distribution is strongly anisotropic, but as the number increases the anisotropy decreases. The arguments cited before lead us to expect a strongly anisotropic angular distribution for secondary protons, which is in accord with the obtained angular distributions and their unsteadiness with a variation of number.

The work of Wan-Szu-Fen and others is a repetition and continuation of work. In work they conducted an identification and measurement of energy only for slow particles (having an ionization greater than 1.4 times the minimal ionization). In work with the aid of the method of Coulomb dispersion and measurement of ionization, an attempt was made to measure the energy and identify the fast particles having an ionization smaller than 1.4 times the minimal ionization. The identification of particles permitted to outline the separate angular distribution of protons and mesons and to give their energy distributions. The angular distribution of secondary protons is strongly anisotropic (Fig 4a, b).

The angular distribution of π mesons also shows a certain anisotropy, although a considerably smaller one (Fig. 5). Figure 6 represents an energy distribution of protons in the rear hemisphere.

The authors of work [2] have at their disposal the same type of material from the statistical point of view as do the authors of work [1] and confirm a number of its conclusions concerning the percentage composition of stars with different numbers, average energy of protons and π mesons, and analogously as in [1] they conclude that the primary proton transfers approximately 35 percent of its energy for the generation of π mesons, which gives a coefficient of inelasticity K = 0.5.

The work of Daniel and others, as well as Kalbach and others, are devoted to analogous problems at an energy of 6.2 BeV. These works are also executed with the aid of the emulsion technique, and the block of emulsion of the Ilford-G5 type was bombarded by a cluster of protons accelerated in a bevatron.

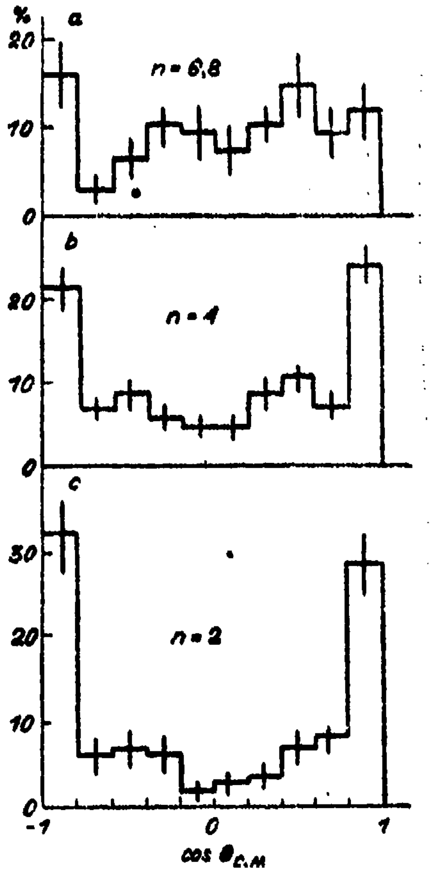


Figure 2a, b, c. Angular distributions of secondary particles in the C.M. system for p-p collisions for different numbers [1]

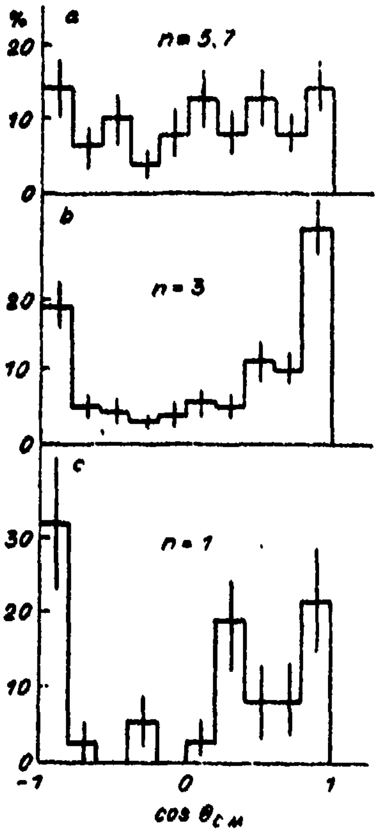


Figure 3a, b, c. Angular distributions of secondary particles in the C.M. system for p-n collisions for different numbers [1]

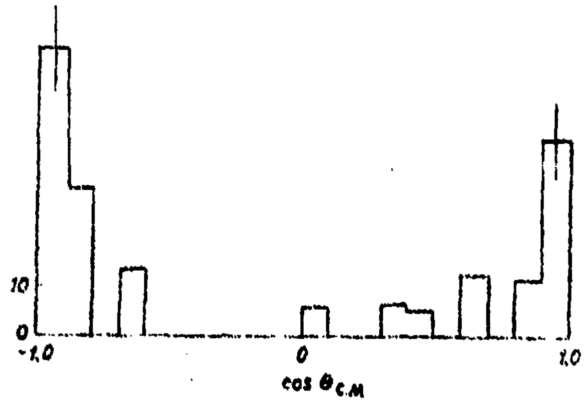


Figure 4a, b. Angular distributions in the C.M. system of secondary protons in p-p and p-n collisions [2]

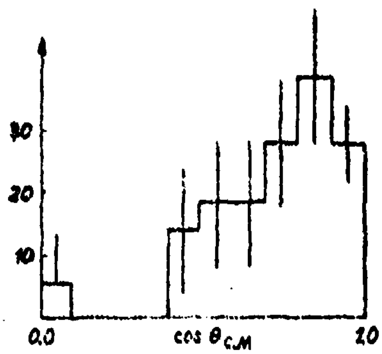


Figure 5. Angular distribution of π-mesons in the C.M. system (boyh halves in the C.M. system are combined on the assumption of symmetry)

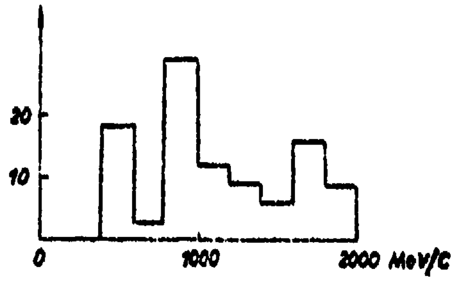


Figure 6. Angular distribution of proton velocities in the rear hemisphere in the C.M. system

In work [3], with the aid of the method of scanning of the traces of primary protons, 491 inelastic collisions were found. Applying generally accepted criteria, 196 of them were recognized as collisions of the proton with a free or quasi-free nucleon. With the aid of the method of ionization measurement and Coulomb dispersion secondary particles were identified and their energies designated. The results of this work can be collected in the following points: the average number of loaded mesons in the proton-nucleon collision is 1.5 ± 0.18. The angular distribution of π mesons in the C.M. system show a certain, it seems, significant anisotropy (Fig 7).

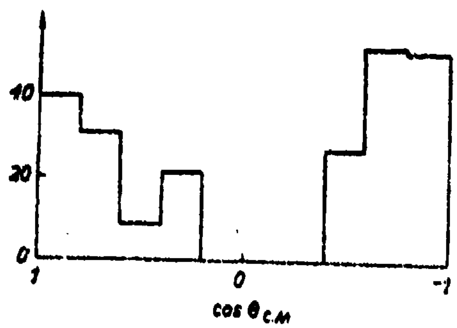


Figure 7. Angular distribution of π mesons in the C.M. system [3]

The average energy of π mesons in the C.M. system is equal to 290 ± 45 MeV. Secondary protons are strongly collimated in the front-rear direction. Identification of particles leads to the conclusion that in the laboratory system at an angle smaller than 10° approximately 70% of the particles are protons and the remainder are mesons, while at an angle greater than 10% only approximately 30% of particles are protons and the remainder are mesons. The coefficient of inelasticity as a ratio of the energy transferred for the generation of mesons to the total energy in C.M. was evaluated by two independent methods: a) from the mean energy and number of π mesons in C.M.; b) from the mean energy of protons after collision. Both these methods give a value of around 0.43 which appears to be independent of the number. These results are in full agreement with those obtained in the work of Kalbach and others, in which 315 cases were selected for an analysis of inelastic p-p collisions. Figures 8a, b, and c represent the angular distribution of protons in stars with numbers 2, 4 and 6.

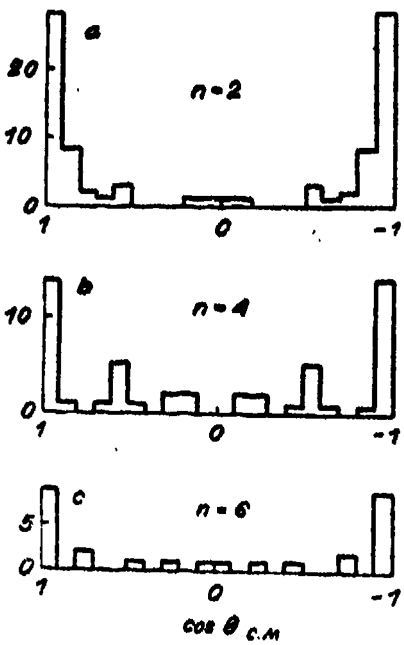


Figure 8a, b, c. Angular distributions of secondary protons from p-p collisions in stars with varying numbers

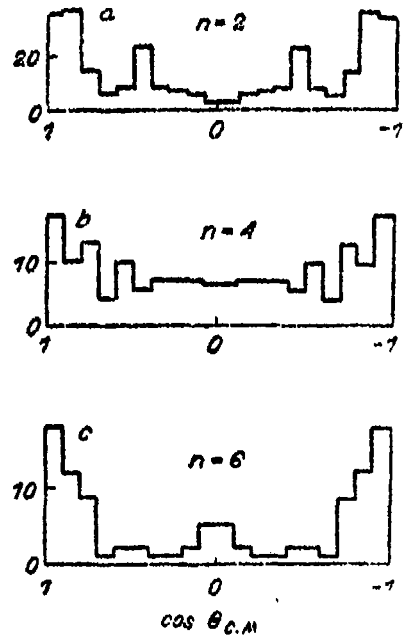


Figure 9a, b, c. Angular distributions of π mesons from p-p collisions in stars with varying number

Figure 9a,b, and c represents the angular distribution of mesons for these numbers.

Graphs 8 and 9 are made on the assumption of ideal symmetry in the C.M. (each particle is counted twice).

Figures 10a,b,c and 11 a, b, c represent velocity distributions of π mesons and protons in the C.M. system. Continuous curves correspond to the expectations of the statistical theory.

The above collected experimental facts concerning inelastic collisions of protons with nucleons were compared, mainly with the results of two theories. One of them was the statistical theory of Fermi, the second theoretical concept, which was proposed indeed in connection with the above experiments is the model of excited nucleons or so-called isobars. For the statistical theory cannot explain a number of the above-cited experimental effects, such as the strong anisotropy in the angular distributions of secondary nucleons, which attempt to preserve their original direction, of velocity distributions of mesons and protons, etc. These facts point to the real part played by the peripheral collisions i.e. such in which we have a relatively small exchange of energy and velocity, and where the colliding nucleons deviate slightly from their original direction. The isobar model attempts to describe such collisions. According to this model, at the

moment of collision, one or both of the colliding nuclei are excited to isobar, short duration states, which later disintegrate independently, with an emission of π mesons. This resonance comes out just for those energies, for which the energy in the system of the center of mass is sufficient for the formation of the rest state mass of the π meson. Thus certain experimental facts, at least in the case of small numbers of the formed mesons, seem to testify in favor of the isobar model. This model encounters, however, a series of difficulties in the interpretation of cases with large numbers.

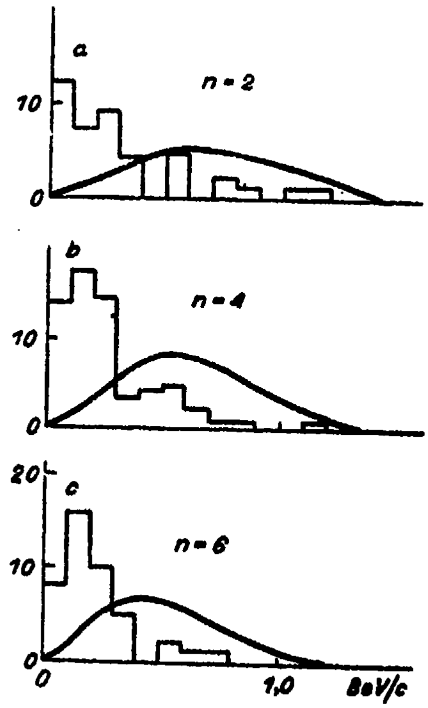


Figure 10a, b, c. Velocity distributions of π mesons from stars with varying numbers in the C.M. system

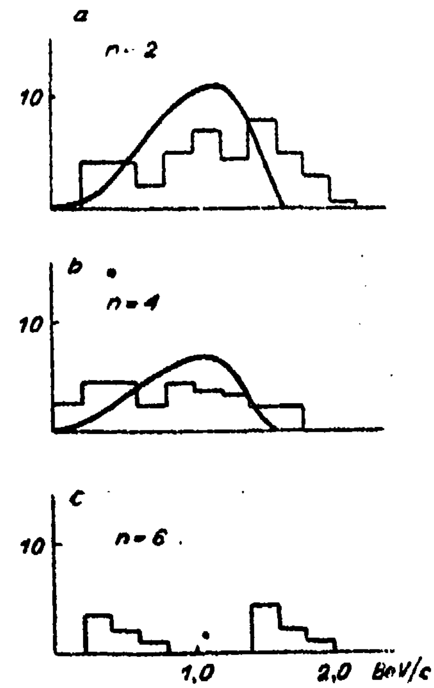


Figure 11a, b, c. Velocity distributions of secondary protons from stars with differing numbers in the C.M. system

π-meson-Nucleon Reaction

An analogous process for the π-meson-nucleon reaction to the production of two mesons in a nucleon-nucleon collision is the production of one meson. For low energies, of the order of 1 BeV, it can be well described by an isobar model, given by Lindenbaum and Sternheimer, which in this case agrees very well with the test (Alles-Borelli et al.).

The process of production of a greater number of mesons becomes applicable only at an energy of several BeV, e.g. for an energy 1.3 BeV, Fowler et al. found very few such cases. Table II gives the number of stars with a different number of sides formed in the reactions of π-meson-proton and π-meson-neutron for various energies.

Table II

Reaction π -n

a Ilość ramion w gwieździe / c Energia (BeV)	1	3	5	7	b z pracy:
1,5	88,7 (55)	11,3 (7)	—	—	[16]
4,5	43,3 (29)	44,8 (30)	11,9 (8)	—	[10]
7	23,1 (56)	59,1 (143)	14,9 (36)	2,9 (7)	[14]

Reaction π -p

Number of stars are in percent, in brackets are absolute numbers

a Ilość ramion w gwieździe / c Energia (BeV)	2 niesl. d	4	6	8	10	12	14	b z pracy:
1,4	95,8 (91)	4,2 (4)	—	—	—	—	—	[2]
1,5	95,7 (22)	4,3 (1)	—	—	—	—	—	[15]
4,5	66,3 (65)	28,6 (28)	5,1 (5)	—	—	—	—	[10]
5	60,4 (64)	36,8 (39)	2,8 (3)	—	—	—	—	[11]
7	50,8 (142)	43,6 (122)	5,0 (14)	0,6 (2)	—	—	—	[14]
16	9,2 (12)	51,5 (67)	28,5 (37)	9,2 (12)	0,8 (1)	— 0	0,8 (1)	[17]

/ Key to Table II: / a) Number of sides in the star; b) From work; c) Energy (BeV) d) inelastic

Despite such a pronounced change in the character of the process in the energy region of interest to us, the entire section active in the π-meson-nucleon reaction changes slowly with energy; the section active in elastic collisions decreases, while the section active in inelastic reactions is practically unchanged (Table III).

Walker's work is devoted to the problem of the interaction of π^- mesons having an energy of 4.5 BeV with nucleons. He searched for interactions of this type in a packet of nuclear emulsions, bombarded with a cluster of π^- mesons from a Bevatron. He found 128 collisions, recognized as an interaction π^--p, as well as 68 interactions, recognized as π^--n. Naturally, all interactions of this latter type, as well as also a portion of the proton interactions, apply to quasi-free nucleons. Walker measured the angles of secondary particles, the ionization and Coulomb dispersion. This made it possible to establish the energy and to identify a certain number of secondary particles. The results of Walker do not differ much from the results obtained by Maenchen et al.

Table III

E (BeV)	σ_t mb	σ_{el} mb	a) z pracy:
1,3	$26{,}4 \pm 2{,}2$	$7{,}4 \pm 1{,}0$	[7], [13]
1,4	29 ± 3	$7{,}0 \pm 1{,}0$	[8], [9]
4,5	$28{,}0 \pm 2{,}6$	$6{,}0 \pm 1{,}5$	[10]
5	$22{,}5 \pm 2{,}4$	$4{,}7 \pm 1{,}0$	[11]
6,8	30 ± 5	$5{,}5 \pm 0{,}5$	[12]

[Key to Table III: /a) From work

The authors of this work analyzed 15,000 pictures taken from a hydrogen diffusion chamber lighted by a cluster of π^- mesons with an energy of approximately 5 BeV. The chamber was placed in a magnetic field. Altogether 135 collisions of mesons with protons were found. The angles of the secondary particles, the curvatures of the tracts and the ionization were measured; this last measurement permitted the identification of a considerable part of the positive particles; all the negative particles were recognized as π^- mesons. Each case was transformed to the system of the center of mass of the π-nucleon, making a balance of velocity and energy; this permitted to establish angles, energies and masses of the possible neutral particles. The angular distributions and velocity distributions, obtained in the works of Walker and Maenchen are given in Figures 12-23.

Conclusions from both of the above works appear as follows: for two-sided, inelastic stars, in which at most one charged meson is produced, there is visible a strong spearheading frontwards in the system of the center of mass of mesons, while in the case of protons, it is backwards.

The velocities of the particles produced in these collisions are higher than of the particles produced in multisided stars. This concept is in clear contradiction with the isobar model, at any rate, with model 3/2, for which the supplementary meson should fly rather together with the nucleon, and therefore in our case it should fly to the rear in the system of the center of mass π^--N. This is also apparent clearly for a certain number of interactions π^-+n+2 π^-+p in which the produced meson flies together with the primary meson in a direction opposite to the flight of the proton. Walker suggests that this is a result of the interaction or rather of the collision of the π meson with the π meson from the meson cloud of the nucleon (model of Dyson and Takeda for 1BeV).

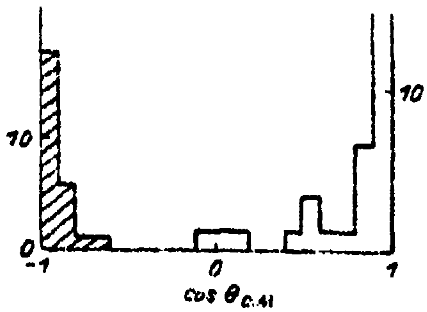


Figure 12. Angular distribution of protons and π^- mesons from the reaction: $\pi^- + p \rightarrow \pi^- + p + ?$ (in the C.M. system). The protons were cross-hatched

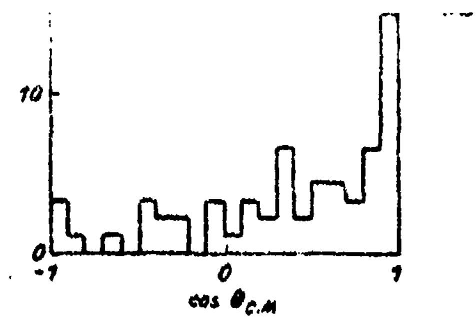


Figure 13. Angular distribution of mesons from the reaction: $\pi^- + p \rightarrow \pi^+ + \pi^- + N + ?$ (in the C.M. system)

Figure 14. The angular distribution of the identified protons from two-sided stars (in the C.M. system)

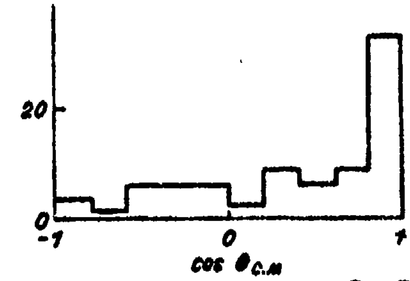


Figure 15. Angular distribution of π^- mesons from two-sided stars (in the C.M. system)

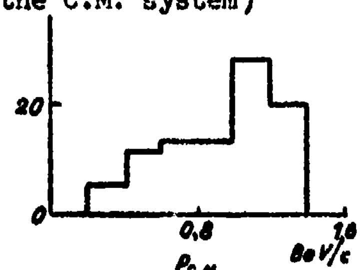


Figure 16. Distribution of proton velocities from reaction $\pi^- + p \rightarrow \pi^- + p + ?$

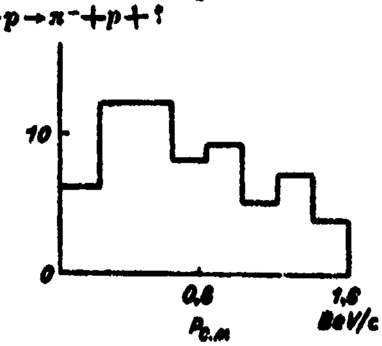


Figure 17. Distribution of velocities of π^- mesons from two-sided stars.

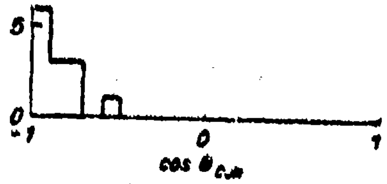


Figure 18. Angular distribution of protons from four-sided stars (in the C.M. system)

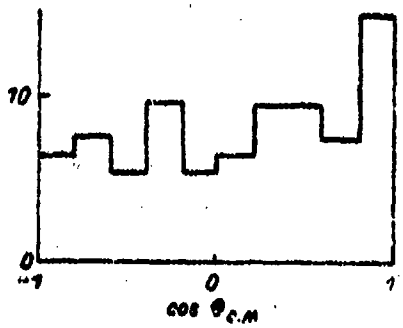


Figure 19. Angular distribution of π^- mesons from four-sided stars (in the C.M. system)

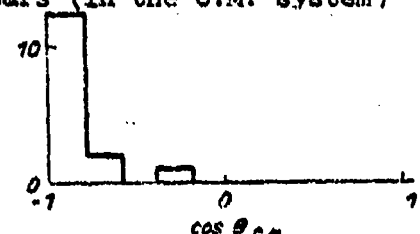


Figure 20. Angular distribution of the identified protons from four-sided and six-sided stars (in the C.M. system

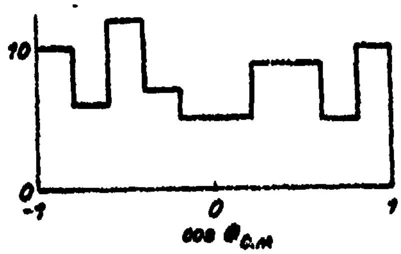


Figure 21. Angular distribution of π^- mesons from four-sided and six-sided stars (in the C.M. system)

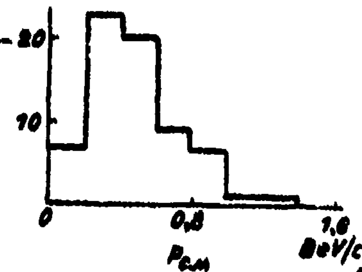


Figure 22. Velocity distribution of π^- mesons from four-sided and six-sided stars (in the C.M. system)

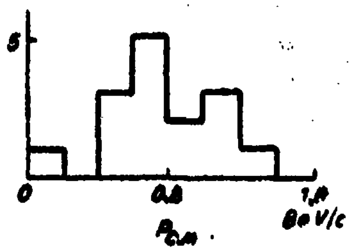


Figure 23. Velocity distribution in the C.M. system of identified protons from four-sided and six-sided stars

Qualitatively, this model well explains the production of one or two mesons through the $\pi - \pi$ interaction.

For many-sided stars Maenchen, as well as Walker, observe a strong asymmetry of protons, which, as before, exhibit a tendency towards the preservation of the direction of flight in the system of the center of mass. The mesons show small deviations from symmetry and isotropy, and the velocity of mesons flying frontwards is somewhat greater than those flying backwards. In figures 24 and 25 are represented angular distributions of mesons from four-sided and six-sided stars after dividing them into groups with a velocity greater and smaller than 600 MeV/c.

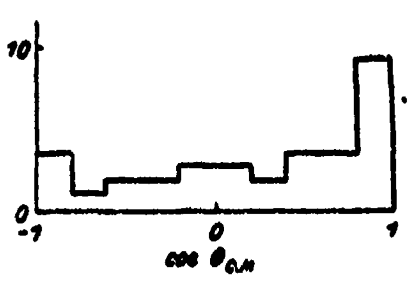


Figure 24. Angular distribution of π^- mesons with velocities ≥ 600 MeV/c from four-sided and six-sided stars (in the C.M. system)

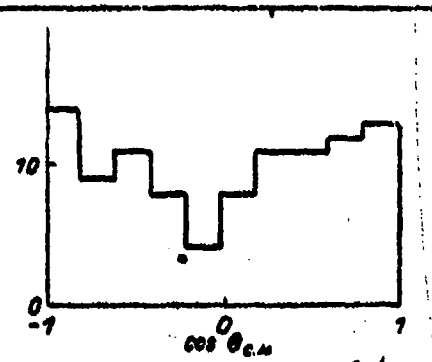


Figure 25. Angular distribution of π⁻ mesons with velocities $\leq$ 600 MeV/c from four-sided and six-sided stars (in the C.M. system)

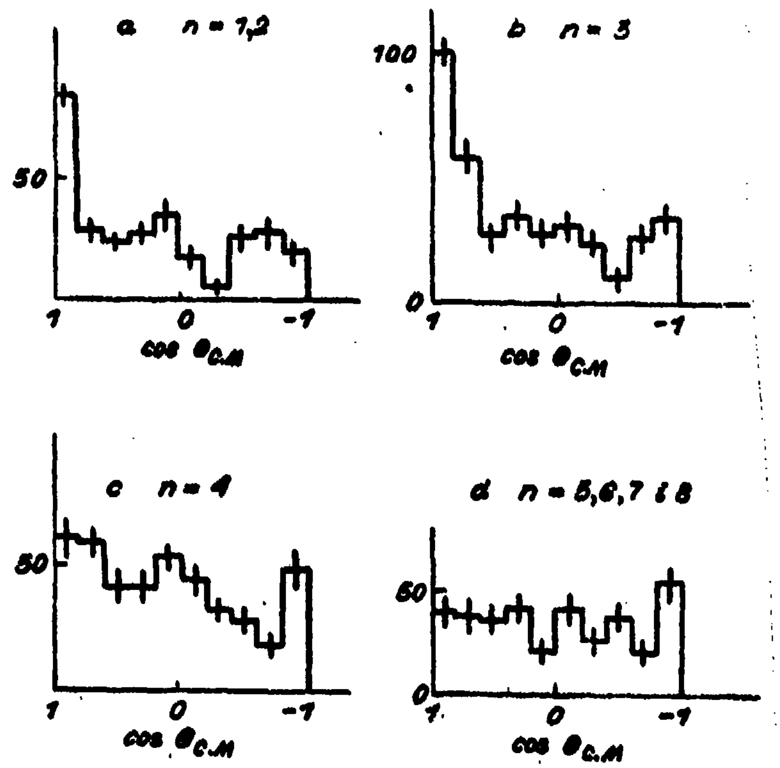


Figure 26a, b, c, d. Angular distributions of π mesons from stars with different numbers (in the C.M. system)

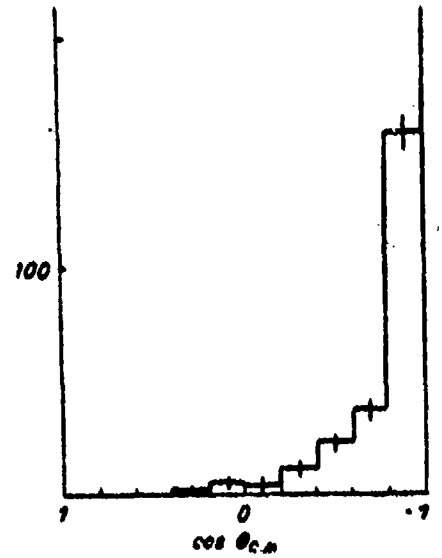


Figure 27. Angular distribution of secondary protons from all stars (in the C.M. system)

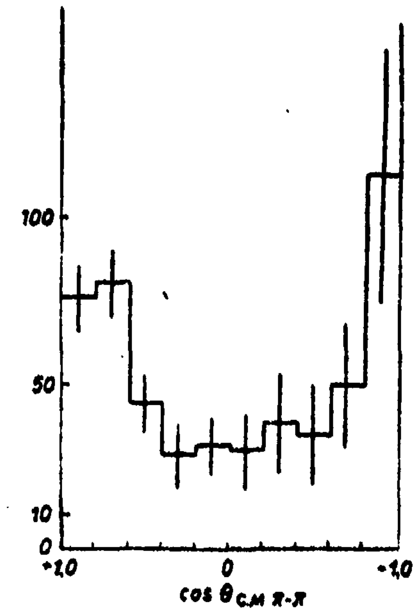


Figure 28. Angular distribution of mesons with velocities ≥ 0.5 BeV/c in the system of the center of mass π - π

The production of a greater number of mesons is a phenomenon more difficult to interpret, even qualitatively, than individual production; at any rate, the statistical theory of Fermi, which anticipates a symmetry of angular distributions, fails here. Walker suggests the following interpretation of the phenomenon: the meson, interacting with the nucleon "knocks-out" from its meson cloud one or two mesons, simultaneously exciting the nucleon, which on disintegrating sends out further mesons. The knocked-out mesons fly to the front, those sent out by the nucleon fly together with it to the back, the totality gives an approximate symmetry and isotropy. Such a picture does not, of course, pretend to be precise.

For an energy of 6.8 BeV, the π^--n interaction was studied by the method of nuclear plates by Bialakow et al in Dubna. They found 293 interactions of mesons with protons and 242 with neutrons. The picture which they obtained does not differ qualitatively from the picture for 5 BeV. The protons preserve their direction of flight in the system of the center of mass, while the mesons in low-numbered stars are spearheaded to the front and in high-numbered ones are close to isotropy (Figs 26-27). If all mesons were divided into two groups -- those with velocities lower and higher than 0.5 BeV/c -- and then the latter were to be placed in the system of the center of mass π^- - π^- (this second π^- meson is a "virtual" π^- meson of the meson cloud of the nucleon), then in this system we shall obtain a symmetrical and an anisotropic distribution (Fig 28). The authors consider that this fact testifies to it that at least a part of the mesons is produced by an interaction of π^- - π^-.

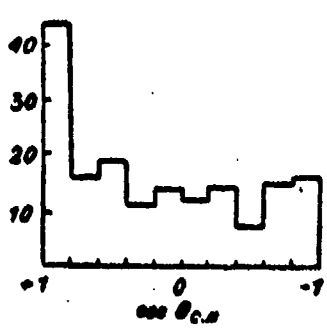


Figure 31. Angular distribution of all π^- mesons from the interaction π^--p for the primary energy ~ 16 BeV

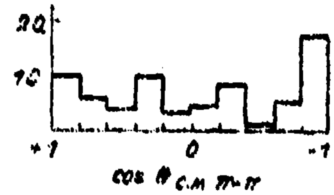


Figure 32. Angular distribution of mesons with velocities of ≳ 0.6 BeV/c in the system of the center of mass π -

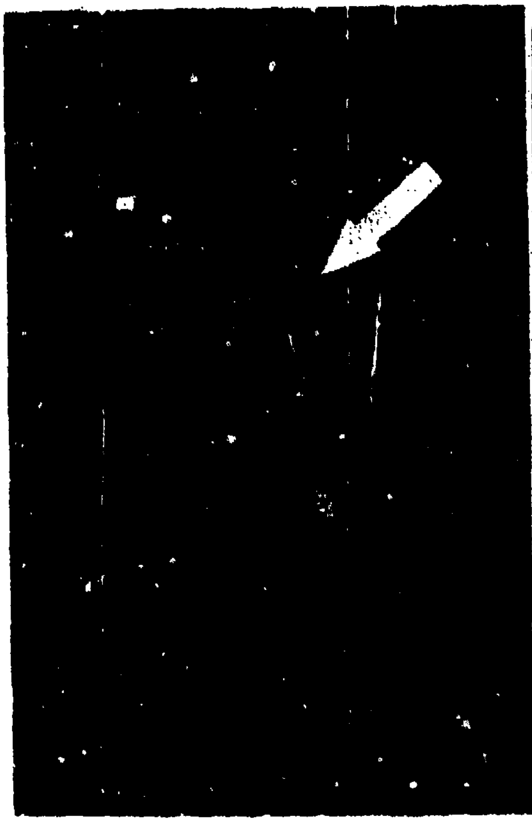
Also for considerably higher energies, namely for π^- mesons with a velocity of 16 BeV/c interacting with protons in a hydrogen bubble chamber (Figs 29 and 30)[4], the phenomenon of generation of mesons appears similar. On Figure 31 there is given the angular distribution of ¯ mesons from 70 of this type stars obtained by Bartke. If mesons are selected in the center of mass -p with a velocity greater than 0.6 BeV/c, and then transformed to the - system, then the distribution given on Figure 32 is obtained. The symmetry of this distribution testifies, in the opinion of the authors, in favor of π^- - π^- interaction.

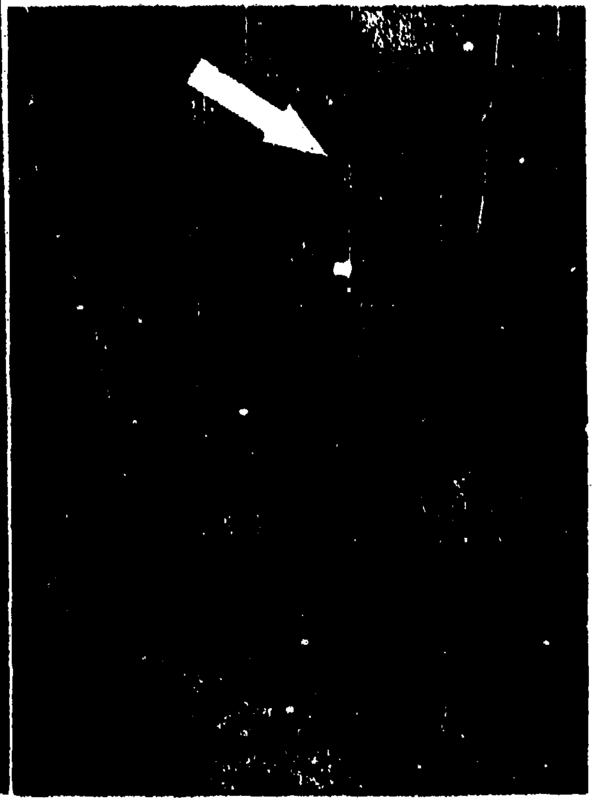
π-meson-Nucleus Interaction

The interaction of π^--meson-nucleus was studied for an energy of 4.5 BeV by H. H. Aly et al. The packet of nuclear emulsions was exposed to a cluster of π^- mesons from the Bevatron. Two hundred interactions of mesons with emulsion nuclei were found. The authors measured the relativistic angles of the secondary particles and where the position of the track in the plate permitted it, also the ionization and Coulomb dispersion. All the stars were classified according to the number of "black" and "gray" tracks (N_h) and tracks with a minimum ionization (n_s).

The authors divide the entire material into two groups: stars with a $N_h \leq 7$ which corresponds to collisions with protons, light nuclei and peripheral collisions with heavy nuclei and stars with $N_h > 7$ which corresponds to collisions with heavy nuclei. These groups clearly differ in the laboratory angular distributions. The half-angle, for $N_h > 7$, $\vartheta_{1/2} = (43.2 \pm 4.2)^\circ$, while for the collisions for $N_h \leq 7$, $\vartheta_{1/2} = (27.0 \pm 2.7)^\circ$. As can be seen, the difference is significant. The authors, analyzing this fact, suggest that the second case concerns a collision with a "heavier partner": the number of nucleons interacting with the meson π would in this case have been greater. Assuming symmetry in the system of

[4] The authors thank Magister J. Bartke of CERN for the transmittal of photographs.





Figures 29 and 30. Stars from π^--p interaction in a hydrogen bubble chamber (CERN) Energy of primary mesons $\sim$ 16 BeV

the center of mass, the authors establish the mean mass of the partner in the collision for both groups. The results appear as follows (in units of proton mass):

$$N_h > 7 \quad M = \left(2{,}38 \pm {0{,}9 \atop 0{,}4}\right) m_p$$

$$N_h \leq 7 \quad M = \left(0{,}77 \pm {0{,}36 \atop 0{,}19}\right) m_p .$$

The angular distribution in a thus obtained center of mass is, of course, symmetrical, and is noted for a clear anisotropy (Fig 33). The authors, unfortunately, do not give the anguler distributions for various number, hence their comparison is not possible.

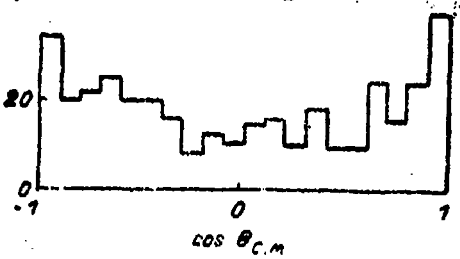


Figure 33. Angular distribution of secondary particles from the interaction π^--nucleus for an energy of 4.5 BeV (in the system of center of mass)

The fact that the "mass of the partner" for collisions with a heavy nucleus is greater than for the remaining collisions does not have to testify to this being a collision with more than one nucleon at a time as it is suggested by the hydrodynamic theory. If the collision mechanism is of a "cascade" type, the result will be the same.

Conclusions

As it seems, the following characteristics are common for the interactions π-nucleon and nucleon-nucleon in the region of energy of 5-10 BeV: nucleons, independently of the number of mesons produced, preserve their direction of flight, while the velocities of nucleons and mesons are the greater as less mesons are produced. Mesons are produced more isotropically in the system of the center of mass, and the anisotropy decreases with the quantity of mesons. Statistics, which are free of doubt, are not too extensive. Angular distributions, as well as velocity distributions, are inexact, and the picture of the changes of these distributions with energy is incomplete.

The theoretical interpretation of the above discussed results is not in the least satisfactory. The statistical theory surely does not explain them, the most important divergence with it being the fact of asymmetry in the interactions π-nucleon and proton-neutron. Whether the isobar model can explain these phenomena it cannot yet be said; certain attempts of this nature (Tamm, Czerniawski) seem to testify that this is possible. A second possibility is the search for a solution by way of introduction of the structure of a nucleon, which is surely engaged in some manner in the process of a multiple generation of mesons. If the preservation of the direction of flight of nucleons is a characteristic property of the peripheral collisions of nucleon-nucleon or π-nucleon, then the fact alone that there are many such collisions - that they are in a majority - is in itself very interesting. If we assume that the peripheral collision is a collision with the "meson cloud" of the nucleon, we must arrive at the conclusion that the dimensions of the root of the nucleon, the "core", are small in comparison with the dimensions of the nucleon.

Also, though indirectly, information on the structure of the nucleon can be furnished by the study of the interactions of nucleons or mesons with nuclei. Up to now the matter of mechanism of interaction with the nucleus has not been resolved, especially the interaction with the heavy nucleus, for the energy range of interest to us. Entering into play here could be a mechanism of the cascade type, successive collisions with increasingly lower energies inside the nucleus or some mechanism of simultaneous interaction with a greater quantity of nucleons. In the first, as well as in the second case, the results must depend on the type of the assumed interaction with the individual nucleon, and hence on the assumption of some nucleon structure.

The problem of multiple generation at accelerator energies is therefore an open problem. A series of studies are conducted in this field, primarily at the Institute for Nuclear Studies in Dubna, which has at its disposal protons of an energy of 9 BeV and π^- mesons of an energy of 8 BeV. Recently studies in this subject were started in CERN where, thanks to protons of an energy of 30 BeV and mesons of 16 BeV, the region of energy included in the studies has widened considerably. Information received up to now in this field from cosmic radiation which will remain for a long time, if not forever, the only source of information about the highest energies, are not by the nature of the thing complete due to a lack of precise data about the energy of the primary particle, and in the interval of accelerator energies phenomena are outlined which were previously seen only for energies higher than 10^{11}eV, e.g. the anisotropy of angular distributions or the small coefficient of inelasticity in n-n collisions.

In the USSR there is currently an accelerator being built which will accelerate the protons to an energy of 50 BeV, which will again widen the region of energy for which a precise study of the process of multiple production of mesons is possible. This does not at all mean that the lower energies do not continue to be interesting. As we mentioned already, statistics are far from satisfactory even for low energies and repetition of these studies with a collection of wealthier material would be very desirable.

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